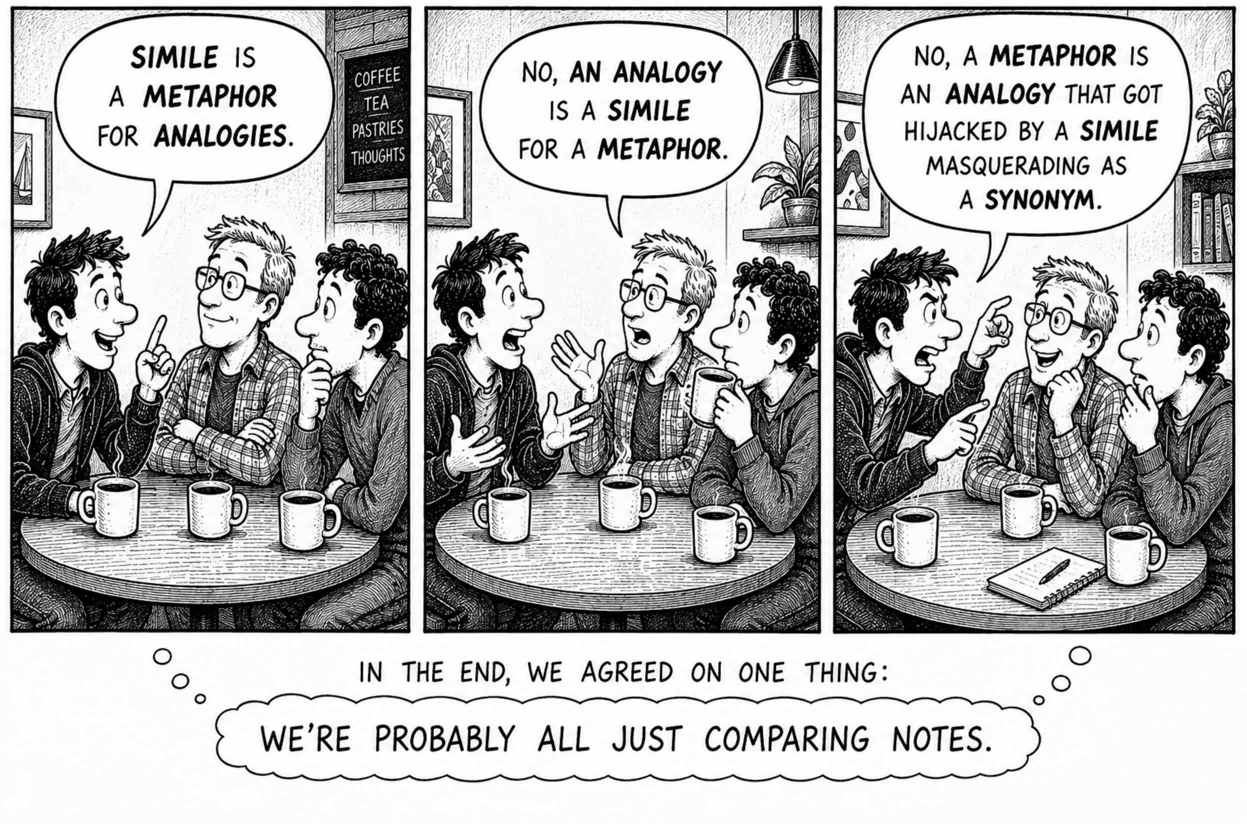
Chapter 19

“Quantum Optics”



Analogies

Freshman year, spring quarter, my roommate and lab partner discovered to our chagrin that we were behind in submitting our physics lab reports – by nine weeks?! Worse, the notes we had taken during the experiments were either crummy or missing, and the lab apparati had already been returned to the storeroom, so we could not repeat the experiments. Oops.

So, while my partner in crime drafted bogus lab reports, I grabbed a stack of paper and my trusty HP35, derived the error equation for each experiment, and used them together to *make up data* with realistic averages and standard deviations, which we inserted into the reports. It took an entire day; there went our Saturday. We submitted on Monday; the grad-student/lab-assistant reviewed them and returned our grades on Friday. You can see where this is going.

I thought so too and was reviewing the course catalog for summer lab classes when the grades arrived, and to my horror, we passed, with flying colors, like they were all ‘A’s. As in “this isn’t right, we should have been caught, we shouldn’t have gotten away with this. What kind of honky-tonk institution are we attending?”

Now for those Intrepid Readers with a moral compass that points due north, it might occur to you that this little enterprise slipped over the proverbial ethical line. Making up data in science is like the ultimate sin. After 50 years, I can finally confess.

It has been said that humans are not rational animals, they are *rationalizing* animals. Now the purpose of a grade is to indicate the level of competence. If my future destiny was as an *experimental* physicist, that grade failed to indicate my true level of competency, and I am guilty as charged. However, … if my future destiny was as a *theoretical* physicist, that grade succeeded in indicating a level of theoretical mastery, the ability to predict the outcome of an experiment. Thus, do I rationalize.

But the past has a pernicious habit of refusing to stay put.

It is therefore, with some trepidation, that I attempt to write a chapter describing the kinds of optical equipment that might be necessary to experimentally test the, *ahem*, theoretical ideas we have been discussing.

The backbone of a quantum optics experiment is the optical bench, a ridiculously large slab of metal, counter height, with enough threaded holes that to count them might require scientific notation. The task is to create photons, torture them in imaginative ways, and then detect them.

This takes a lot of craft.

The typical way to create photons with controlled properties is with lasers. To create entangled photons requires running the laser beam through a nonlinear crystal, such as beta Barium borate (BBO). On occasion, a photon will be split by this crystal into two photons, which take slightly divergent paths, a process called spontaneous parametric down conversion. If the BBO is cut at the 2nd harmonic, the two down converted photons will have the same frequency (half that of the laser). Additional optical elements can be used to generate entanglements in any of the four Bell states. The rate of production of EPR pairs is small, the best techniques achieve about 4 pairs per million incident photons. Intense laser beams are required, but too intense a beam will melt the crystal.

To get two pairs, requires either a second BBO crystal, or using a mirror to reflect the beam back into the original BBO crystal a second time. Fiber optic cables will direct the EPR photons to single photon detectors, which have dismal efficiencies well below 50%. Most of the time, only one pair is produced, only some of the photons produced are detected, so coincidence counters are used to log only the rare cases when everything worked out as intended. To overlap the wave functions of a pair of photons requires very fast pulsed lasers, pulse shapers, tunable paths, and more.

Bless those gifted at experimental physics.

To flip the polarization, a photon must be diverted through a waveplate, an optical device made of a birefringent material, such as calcite. Birefringent crystals have two indexes of refraction which can be used to shift the phase of the polarization components of a photon. A quarter-wave plate will convert linearly polarized light into circularly polarized light, and a half-wave plate will rotate the plane of polarization by 90°. The thickness of these plates is driven by the frequency of the light and the difference between the two indices of refraction. Combined plates can be engineered which will shift a small range of frequencies. Fortunately, these devices are all commercially available.

A beam splitter is a half-silvered mirror with a 50% chance of transmitting or reflecting an incoming photon. A polarizing beam splitter does the same but reflects one polarization and transmits the other. The latter is often used in constructing a Mach-Zehnder interferometer, useful in producing interference.

Optical delay devices can be used to switch between distinguishable and indistinguishable measurements, and a half-wave plate to rotate the plane of polarization, but in practice are tricky to use without messing up the timing.

Put these together in all the right ways, account for ambient temperature and humidity, vibration, component heating and expansion due to intense laser beams, manufacturing tolerances, and along with a team of competent experimentalists, it just might be possible to ask mother nature if entangled photons are subject to indistinguishability statistics.